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Features of Optical Characteristics of Atmospheric Aerosol in the Middle Urals

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Abstract—The results of studies into the aerosol optical depth (AOD) for the atmosphere in the Middle Urals in the spectrum range of 0.34–1.02 μm for 2004–2010 is presented. The interannual, annual, seasonal, and daily variations in the AOD are analyzed. The major statistical characteristics of the AOD, the parameters of the probability density function of distributions over different wave lengths, and the parameters of Angstrom's formula for the different seasons are calculated. The monitoring stations in the Russian segment of the AERONET network are ranked with respect to the AOD value. A shift from March to May in the spring maximum of the AOD is revealed in comparison with the results of the actinometric observations for the period of 1960–1986. A qualitative assessment is given to the influence of forest and peat fires in the region on the AOD. A classification of the states of aerosol haze in the atmosphere according to the AOD values is proposed.

Keywords: atmosphere, aerosol optical depth, aerosol, monitoring, AERONET

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1. INTRODUCTION

The regular spectrum measurements of optical aerosol characteristics were first started in June 2004 in the Middle Urals under the AERONET program of Global Atmospheric Aerosol Monitoring (http://aeronet.gsfc.nasa.gov) with the assistance of the Goddard Space Flight Center (GSFC/NASA, United States) and the Zuev Institute of Atmospheric Optics, Siberian Branch, Russian Academy of Sciences [1, 2]. The optical characteristics of the atmospheric aerosol are jointly studied by specialists from the Institute of Industrial Ecology, Ural Branch, Russian Academy of Sciences, and the Ural Federal University. The measurements are carried out by a sun-sky Cimel CE-318 photometer mounted at the Kourovka astronomical observatory. This monitoring station is designated as Yekaterinburg in the AERONET information system.

Some characteristics of aerosol optical depth of the atmosphere (AOD) reconstructed by the data of actinometric observations in the area of the city of Yekaterinburg were presented in [3]. Our work compares the annual variation in the AOD in the Middle Urals for the period of 2004–2010 and the data obtained by the actinometric observations in 1960–1986 [3].

The results of measurements for the atmospheric AOD in the Middle Urals in the spectrum of 0.34–1.02 μm are generalized for the period of 2004–2010. Previously, there have been no spectral photometric measurements in the Middle Urals. The interannual and annual variations in the atmospheric AOD, as well as features of the daily variation, are determined. A qualitative assessment is made for the influence of intense forest fires on the turbidity of the regional atmosphere. The data have of great value for estimating the optical parameters of the atmospheric aerosol, since they characterize a very big region in Eurasia (the nearest monitoring stations of the AERONET network are located in the west in Moscow, in the east in Tomsk, in the south in Dushanbe, and there are none in the north).

2. EXPERIMENTAL CONDITIONS AND SCOPE OF DATA

The Kourovka astronomical observatory of the Ural Federal University (57.036° N, 59.546° E) is located in the forest near the Sloboda village in Sverdlovsk oblast, approximately 65 km northwest of Yekaterinburg. The Cimel CE-318 photometer is mounted on the roof of the solar pavilion of the observatory at a height of ~5 m above the soil level (~295 m above sea level). The Chusovaya River flows close to the monitoring point, which causes fog to appear frequently in summer and autumn. In general, the area can be described as “background” with a moderate continental climate [4–6].

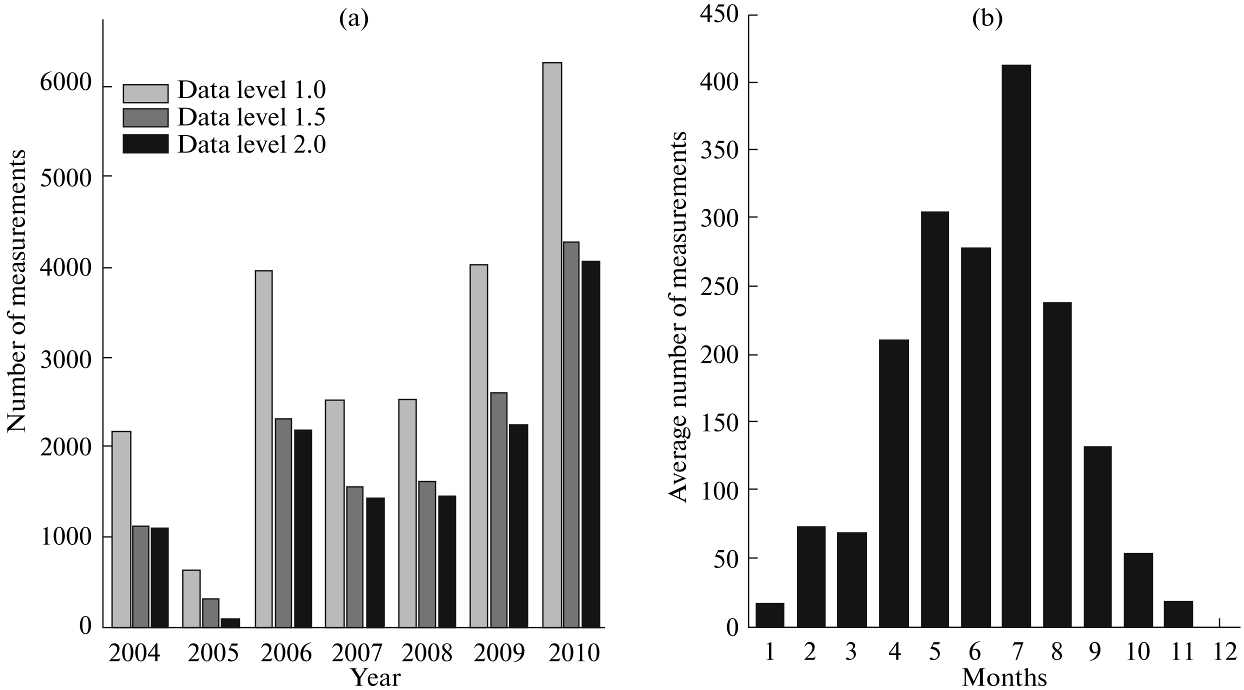

Fig. 1. Availability of measurements: (a) the total number of annual measurements of different levels; (b) the monthly average number of the second level measurements.

Figure 1 presents the annual distribution of the number of the AOD measurement results of different levels and the dynamics of the monthly average number of measurements for the entire monitoring period in the Middle Urals. According to the AERONET classification, the data of level 1.0 include the results of all single measurements; the data of level 1.5 comprise the results without cloud contamination; the data of level 2.0 are the final calibrated measurement results. For the period from May 27, 2004, to November 1, 2010, there were 22151 measurements performed for level 1.0, 13901 measurements for level 1.5, and 12637 measurements for level 2.0 (i.e., about 57% of level 1.0). During winter, there is little photometric information due to the short period of sunshine. Since the average number of measurements in November and January is less than 20, the reliability of the statistical data below is not high for this period.

3. VARIABILITY OF ATMOSPHERIC AOD IN THE MIDDLE URALS

Statistical characteristics of the AOD values. Figure 2 presents typical histograms for the distributions of the results of the AOD measurements made in 2004–2010 for the two lengths of waves. All data presented below belong to level 2.0. As is seen from the figure, the frequency of implementation of the arbitrary AOD value is accurately described by lognormal distribution. The greater the wave length is, the lesser the distribution width is.

Table 1 shows the parameters of the probability density of lognormal AOD distribution in the form

$$\frac{dn}{d\tau} = \frac{1}{(2\pi)^{1/2}\tau \ln \sigma_g} \exp\left(-\frac{(\ln\tau - \ln\tau_g)^2}{2\ln^2\sigma_g}\right), \quad (1)$$

where n is the frequency of the AOD value implementation equal to τ (to simplify writing, the dependence on the wave length is not shown); τ_g is the median value of the AOD and σ_g is the geometrical standard deviation.

We should note that, although the histograms are approximated well by the lognormal function, the Kolmogorov–Smirnov test shows the absence of statistically meaningful differences only for the rows of the daily averaged AODs (the respective parameters in Table 1 are marked in bold font).

The main statistical characteristics for the results of all AOD measurements in the Middle Urals are given in the Summary of Table 2. For comparison, Table 3 presents the results of calculations of the main statistical characteristics of single AODs at a wave length of 0.5 μm in the vicinity of the AERONET stations in Russia (http://aeronet.gsfc.nasa.gov).

In our analysis we used measurement results from only those monitoring stations that provide a series of observations from 2004 to 2010. These data allow us to estimate the characteristics of the aerosol in five different geographical zones, such as the central European part of Russia, the Middle Urals, Western and Eastern Siberia, Yakutia, and the Far East. According to the

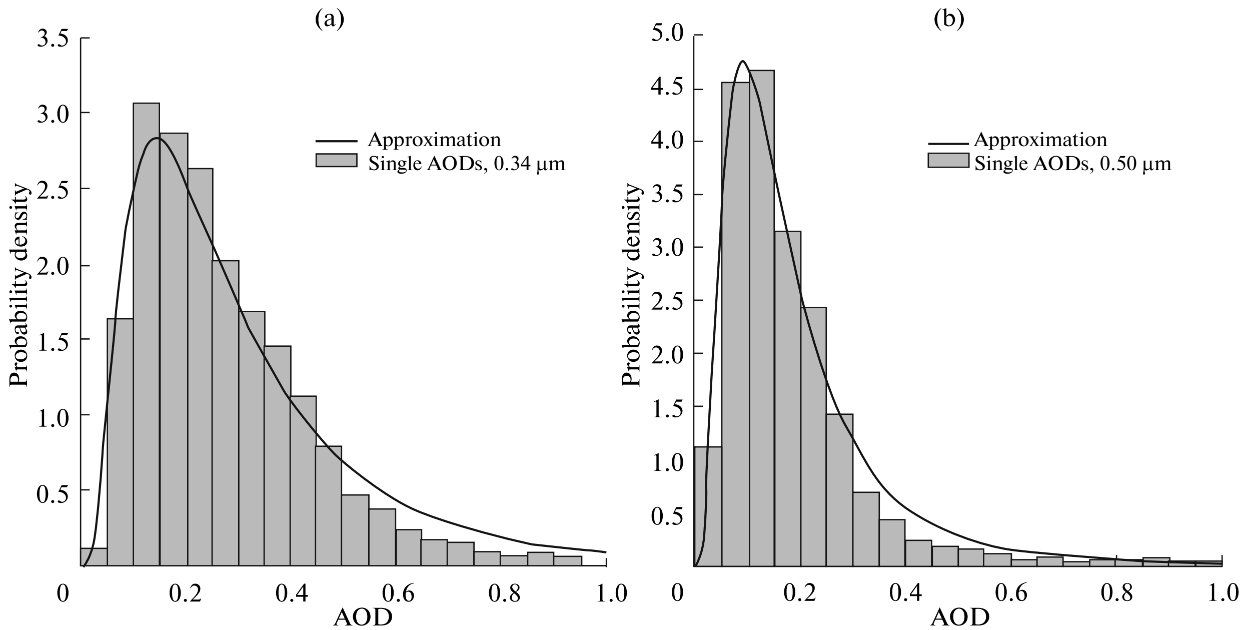

Fig. 2. Histograms and probability density functions of distributions τ_λ for two wavelengths of 0.34 and 0.5 μm.

AOD medians, the stations of the Russian segment in the AERONET network are ranked from largest to smallest as follows: Moscow, Ussuriisk, Yekaterinburg, Tomsk, Irkutsk, and Yakutsk.

Figure 3 shows the spectral behavior for the results of AOD single measurements averaged for the entire period of observations and the yearly seasons. It is seen that the general view of the AOD spectral dependence τ_λ for Yekaterinburg conforms to the data for Western Siberia (the city of Tomsk) [7], though in terms of the absolute value the AOD level in the Middle Urals is somewhat higher for all wave lengths.

This figure also displays the data for different seasons of the year indicating that winter and autumn in the Middle Urals are characterized by the highest atmospheric transparency. However, as we mentioned above, the measured results are the least available in these seasons of the year; therefore, the AOD data should be used with care.

For comparison, Figure 3 illustrates the spectral behavior of the AOD for cases of increased turbidity of the atmosphere caused by forest and peat fires that were identified by the procedure developed in [8].

The spectral behavior of the AOD in the range of wavelengths from ~0.4 μm to ~1 μm is usually represented by the Angstrom formula $\tau(\lambda) = \beta\lambda^{-\alpha}$, where α is a parameter (index) of Angstrom selectivity and β is a turbidity coefficient [7]. Table 4 summarizes the values of parameters from the Angstrom formula that were calculated for all seasons of a year and for the cases of smog caused by forest fires in 2004–2010.

When we describe the properties of atmospheric aerosol, we are certainly interested in the function of aerosol particle size distribution. Figure 4 shows a typical volume function of the particle size distribution, which was reconstructed by the data of spectral measurements (http://aeronet.gsfc.nasa.gov).

Table 1. Parameters of the probability density function of lognormal distribution of single and daily average AOD values

Parameter		Wave length, μm						
		0.34	0.38	0.44	0.50	0.675	0.87	1.02
Single value	$\ln\tau_g$	−1.3859	−1.5296	−1.7151	−1.8956	−2.3923	−2.6905	−2.9297
	$\ln\sigma_g$	0.7430	0.7153	0.7189	0.7252	0.7662	0.7334	0.7635
Daily average values	$\ln\tau_g$	**−1.392**	**−1.5234**	**−1.7013**	**−1.8774**	−2.3621	**−2.6614**	**−2.8689**
	$\ln\sigma_g$	**0.6575**	**0.6619**	**0.6626**	**0.6674**	0.7081	**0.6854**	**0.6875**

Table 2. Statistical characteristics of the results of single measurements of AODs at different wave lengths in the period from 2004 to 2010

Parameter	Wave length, μm						
	0.34	0.38	0.44	0.50	0.675	0.87	1.02
Minimum	0.026	0.027	0.026	0.021	0.007	0.006	0.0005
1st quartile, (τ_λ^*)	**0.153**	**0.133**	**0.111**	**0.093**	**0.055**	**0.041**	**0.033**
Average	0.325	0.288	0.242	0.203	0.127	0.092	0.073
Median	0.243	0.211	0.175	0.145	0.090	0.066	0.052
3rd quartile, (τ_λ^{**})	**0.384**	**0.334**	**0.275**	**0.229**	**0.142**	**0.103**	**0.082**
Maximum	4.337	4.087	3.646	3.157	2.009	1.285	0.946
Standard deviation	0.304	0.286	0.251	0.218	0.142	0.096	0.073

Curve *1* corresponds to the state of the atmosphere with a small content of aerosol. The shape of the function of particle size distribution with $\tau_{0.5} = 0.88$ corresponds to the case when the atmosphere showed a haze caused by a forest fire (curve *2*). Curve *3* refers to a large-disperse aerosol dominating in the atmosphere. According to the measurement results, the most typical are functions of particle size distribution with a dominant finely dispersed fraction of aerosol (curves *1*, *2*). The number of cases when the share of coarse-disperse fraction is higher than the share of fine-disperse fraction is small and makes up about 11% of measurements.

The interannual, annual, and daily variation in the atmospheric AOD. The dynamic processes in the atmosphere, natural phenomena followed by the aerosol generation (dust storms, forest and peat fires, etc.), as well as the processes of anthropogenic pollution of the atmosphere, lead to a variation in the parameters of atmospheric transparency that is typical of each region and each period of time.

Figure 5 presents a general view of the *interannual variation in the AOD* in the Middle Urals, where the rectangles are limited by the first and third quartiles, and the horizontal lines in the rectangles designate the medians of the retrievals. It also illustrates minimum values and dynamics of the average AOD values for the wavelength of 0.5 μm. The maximum AOD values in each retrieval are denoted by digits at the top of Figure 5. The heights of the rectangles characterize the width of the distributions, since they comprise 50% of all measurements for the respective year.

We note that the data for 2005 with scarce measurements should be considered only indicative. From Fig. 5 is seen that the maximum turbidity of the atmosphere (the absolute maximum $\tau_{0.5} = 3.16$) was recorded in 2010. The highest average annual value of the AOD for the entire period of observations was also in 2010.

Since the AOD distributions are not normal (in such cases the average value is known to substantially depend on the extremum values), in Fig. 5 the average annual AODs vary much more than the median values. Because the maximum AODs may be determined not only by the processes of aerosol pollution of the atmosphere (natural or anthropogenic) but also by

Table 3. Statistical characteristics of the AOD at a wave length of 0.5 μm in the period from 2004 to 2010 for different monitoring stations

Parameter	Moscow	Yekaterinburg	Tomsk	Irkutsk	Yakutsk	Ussuriisk
Minimum	0.024	0.021	0.017	0.017	0.019	0.035
1st quartile, ($\tau_{0.5}^*$)	**0.110**	**0.093**	**0.095**	**0.082**	**0.069**	**0.107**
Average	0.219	0.203	0.175	0.139	0.142	0.227
Median	0.171	0.145	0.138	0.115	0.108	0.158
3rd quartile, ($\tau_{0.5}^{**}$)	**0.271**	**0.229**	**0.204**	**0.166**	**0.162**	**0.263**
Maximum	4.623	3.157	2.051	1.377	2.262	1.965
Standard deviation	0.188	0.218	0.154	0.102	0.148	0.202

Table 4. AODs at the wave length of 0.5 μm and parameter of the Angstrom formula

Parameter	Fires 2004–2010	Summer (without fires)	Summer (general)	Autumn	Winter	Spring
$\tau_{0.5}$	0.482	0.178	0.241	0.136	0.123	0.179
α	1.655	1.540	1.539	1.273	1.237	1.462
β	0.156	0.063	0.084	0.063	0.058	0.066

incomplete filtration of the interfering influence of semitransparent cloudiness [9], we admit that the average values are a less reliable characteristic for the set of the AOD measurements than the medians.

For the same reason, an assessment of the AOD variation by only average values is not complete (the set of statistic parameters in Table 2 is more informative). It seems helpful to introduce three classes of atmospheric transparency and to control the changes in the atmospheric states for each of those classes by analogy with work [10]. Class I is a clean atmosphere ($\tau_\lambda < \tau_\lambda^*$); the AOD takes on values less than the values of the first quartile from the measurement retrieval for the minimum period of time for the climate assessment (approximately 10 years). Class II is an atmosphere with a typical content of aerosol ($\tau_\lambda^* \le \tau_\lambda \le \tau_\lambda^{**}$); the AOD takes on the values between the first and third quartiles of the stated retrieval, which conforms to 50% of all possible states of the atmospheric transparency. Class III is a turbid atmosphere polluted with aerosol ($\tau_\lambda > \tau_\lambda^{**}$; the AOD exceeds the value of the third quartile. It is evident that this classification minimizes the effect of incomplete filtration of cloudiness, especially when analyzing the variation in parameters of atmospheric transparency for the first two classes. All the cases of the state of the Class III atmosphere must be analyzed separately to establish the reasons and conditions for the high turbidity of the atmosphere. The procedure for detecting the cases of high turbidity of the atmosphere caused by forest and peat fires based on an analysis of the AOD spectral measurement results was developed in [8]. The calculations performed by this procedure indicate that each fire case falls within Class III of the aerosol pollution of the atmosphere.

The assessments of the respective boundaries of our classification (the values of the lower τ_λ^* and upper τ_λ^{**} quartiles) for the period of 2004–2010 are presented in Tables 2 and 3 (in bold).

To determine the anomalously high average annual value of the AOD in 2010 (Fig. 5), we performed a simple analysis that shows the AOD variation for the different periods. Figure 6 illustrates the *annual behavior of the main statistic characteristics of the daily average AODs* at a wavelength of 0.5 μm. It also shows the AOD values reduced to a wavelength of 0.5 μm that were reconstructed by the data of actinometric observations in 1960–1986 at the Verkhnee Dubrovo meteostation (located east of Yekaterinburg) [3].

It is seen from the figure that the parameters of the atmospheric transparency have substantial differences in the periods of 1960–1986 and 2004–2010. The act-

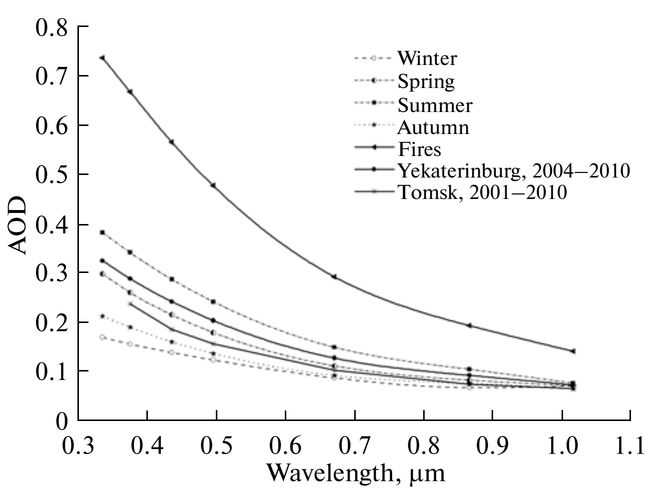

Fig. 3. Spectral dependences of the atmospheric AOD.

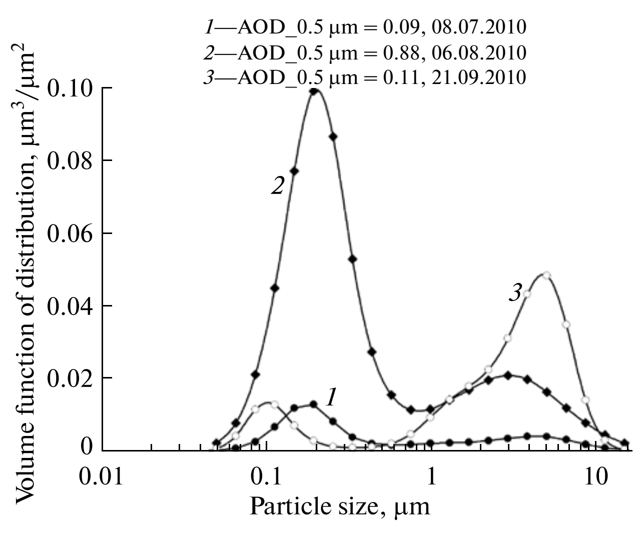

Fig. 4. Typical aerosol particle size distributions.

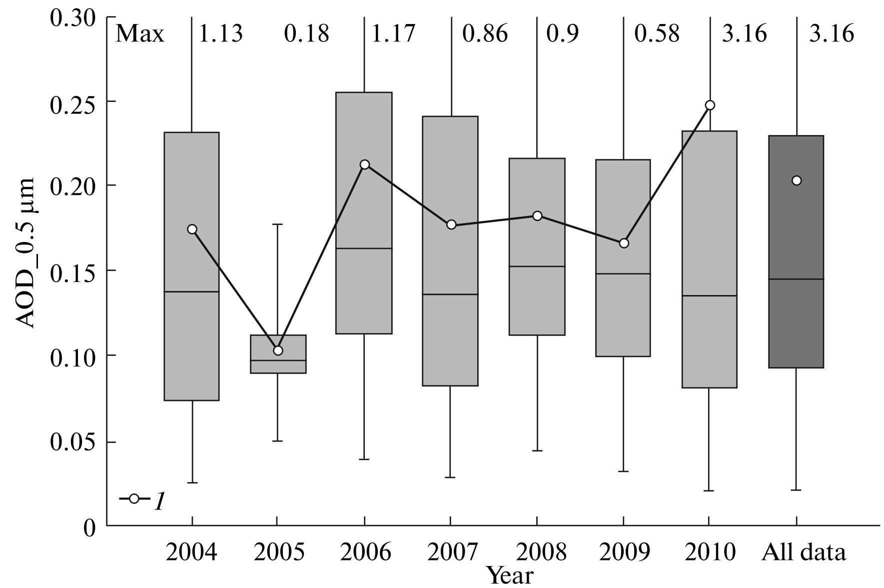

Fig. 5. Interannual variation in the results of single measurements $\tau_{0.5}$; 1 is the annual average values.

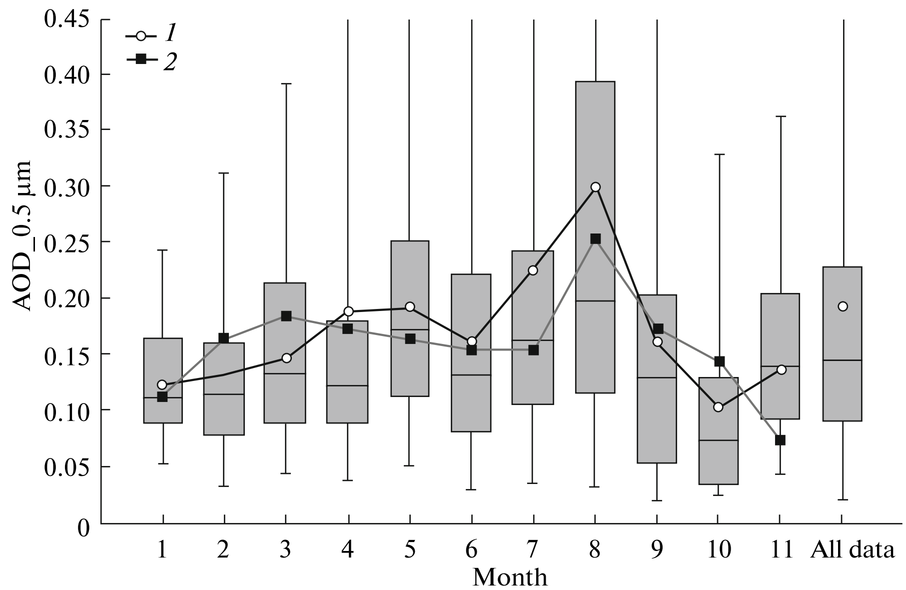

Fig. 6. Annual variation in the AOD; monthly average values in 2004–2010 (*1*) (—) and 1960–1986 [3] (*2*).

inometric observations showed that, for 4 months out of the year, February, March, September, and October, the average AOD values were higher than the current values during the same observation periods. In the other months, the atmospheric transparency around Yekaterinburg got worse when compared with the data for 1960–1986.

We note that the August AOD maximum remained and the spring maximum shifted from March (in 1960–1986) to May (in 2004–2010). In connection with this, several questions arise as to if this phenomenon is local and specific for the Middle Urals or if it is also common for the other regions; what are the reasons for the qualitative and quantitative variation in the parameters of the atmospheric transparency in the contemporary time? The possible hypotheses of the differences are included into three groups: (1) the difference in the observational and data-processing procedures, (2) the change in anthropogenic activity (for example, the change in the system of detecting and fighting forest fires), and (3) climate changes. These questions remain unanswered. Resolving them requires organizing special investigations.

Table 5. Degree of increase in atmospheric turbidity k_λ produced by forest fires

Sample	Wavelength, μm						
	0.34	0.38	0.44	0.50	0.675	0.87	1.02
August 2010	4.8	5.2	5.3	5.5	5.4	4.6	4.3
2004–2010	3.2	3.3	3.4	3.4	3.3	2.8	2.5

From the presented data it follows that, with respect to the aerosol content in the region under consideration, the atmosphere is cleanest in the autumn and winter periods and the spring and summer periods have maximum values and variations in τ_λ, which conforms to the conclusion made earlier on the basis of the AOD spectral behavior and is also consistent with the results of studies by other authors [11].

Turning back to an analysis of the anomalously high aerosol turbidity in 2010, we note that an increase in the annual average AOD value resulted from the measurements made in August. The calculations of the monthly average values of $\tau_{0.5}$ for August in each year show that in 2010 the value of this parameter increased by over 300%. It is well known from the data of visual observations and other sources that in August 2010 the vast territory of the European part of Russia was covered by smog produced by forest and peat fires.

The results of the AOD measurements at the AERONET station were used to qualitatively assess the influence of forest fires on the atmospheric turbidity in the Middle Urals. For each wavelength we calculated the coefficients of the influence of forest fires on the atmospheric transparency $k_\lambda = \tau_\lambda\,(\text{fires})/\tau_\lambda\,(\text{region without fires})$ (Table 5).

Table 5 shows that the fires substantially influence atmospheric turbidity. The influence of the fires is strongest at the wavelength of 0.5 μm. The least effect is recorded at the wavelength of 1.02 μm, though in this case the AOD still considerably increases. It is also seen from Table 5 that the atmospheric turbidity in summer 2010 caused by the fires had an extreme character.

The daily AOD variation is determined by natural processes, first and foremost by daily variations in meteorological characteristics, and may vary in the different seasons. There are different approaches to identifying the daily AOD variation: plotting the graphs of the AOD variations for the middle months of the seasons [11] to exclude seasonal variation and normalizing the hourly average AOD values to the value of the current daily average AOD [12].

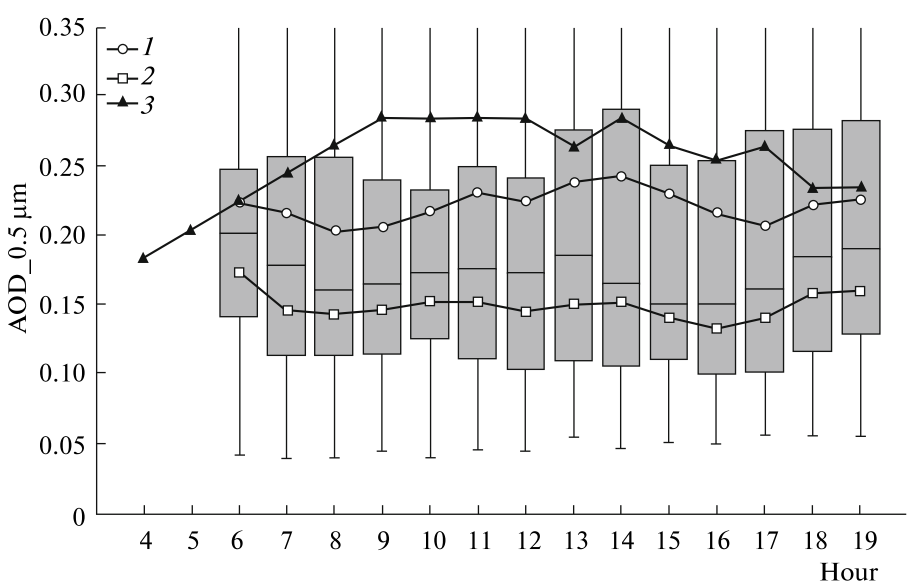

Fig. 7. Daily variation of hourly average $\tau_{0.5}$ in July for the Middle Urals compared to the data for Moscow [11]; (*1*) July, all data; (*2*) July without fires; and (*3*) Moscow [11].

Figure 7 plots the daily variation in $\tau_{0.5}$ for July, the middle month of the summer with the most available measurement results. For comparison, we presented the data on the daily variation in the AOD in Moscow reconstructed by the actinometric observations for the period of 1965–2000 [11].

Figure 7 also displays a daily variation in the hourly average AODs calculated for the sample cleaned of the distorting influence of fires. In this case, the highest AOD value ($\tau_{0.5} = 0.17$) is recorded at 6.00 a.m. and is followed by an almost unvarying smooth behavior of the AOD ($\tau_{0.5} \approx 0.15$) and a weak minimum ($\tau_{0.5} = 0.13$) at about 4.00 p.m. It is worth mentioning that the median AOD values vary similarly for the sample of all measurements, including the cases of fire.

4. CONCLUSIONS

We analyzed the data of 7-year measurements of the atmospheric AODs in the Middle Urals for wavelengths of 0.34, 0.38, 0.44, 0.50, 0.675, 0.87, and 1.02 μm. The results allow us make the following main conclusions.

1. The statistic characteristics of the atmospheric AOD in the Middle Urals and the parameters of the probability density function of lognormal distributions for different wave lengths are determined based on the measurements in 2004–2010. The median value of the AOD at the wavelength of 0.5 μm was 0.145 during the entire measurement period. The comparison (ranking) with the measurement results in other geographical regions allows us to consider the monitoring stations in the Middle Urals and in Western Siberia typically continental.

2. The parameters of the Angstrom formula of the AOD spectral dependence are obtained for different seasons of the year and for the case of high atmospheric turbidity caused by forest fires. For all measurements, including the cases of fire, the Angstrom index of selectivity α and coefficient β have maximum values in the summer ($\alpha = 1.539$ and $\beta = 0.058$) and in the winter ($\alpha = 1.237$ and $\beta = 0.058$).

3. A comparison of the annual variation of the AOD in the period of 1960–1986 and the data of the photometric measurements in 2004–2010 recognized a shift in the spring maximum of AOD from March to May.

4. The influence exerted by the smog produced by intense forest fires on the aerosol turbidity of the atmosphere is assessed. It is shown that the atmospheric AOD may increase 5.5 times in the cases of fire, and the forest fires in the summer 2010 had an extreme character affecting the statistic characteristics of the atmospheric aerosol in the region that were averaged for seven years of measurements in 2004–2010.

5. The daily average variation in the AOD in the Middle Urals in July has a maximum ($\tau_{0.5} = 0.17$) at 6:00 a.m. and a weak minimum ($\tau_{0.5} = 0.13$) at 4:00 p.m. For the rest of the time, the AOD remained almost unchanged ($\tau_{0.5} \approx 0.15$).

6. Based on the values of the first (τ_λ^*) and third (τ_λ^{**}) quartiles of single measurements of AOD retrievals for a decade of observations, it is proposed to identify three levels (classes) of aerosol content in the atmosphere for the entire set of AOD measurements. Class I is a clean atmosphere ($\tau_\lambda < \tau_\lambda^*$, class II is an atmosphere with a typical content of aerosol ($\tau_\lambda^* \le \tau_\lambda \le \tau_\lambda^{**}$), and class III is an atmosphere polluted with aerosol ($\tau_\lambda > \tau_\lambda^{**}$). The preliminary estimates of boundaries to the classes for the 7-year period of observations were obtained for the Middle Ural regions ($\tau_{0.5}^* \approx 0.09$, $\tau_{0.5}^{**} \approx 0.23$) and other geographical regions of the country.

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REFERENCES

1. S. M. Sakerin, D. M. Kabanov, M. V. Panchenko, V. V. Pol'kin, B. N. Holben, A. V. Smirnov, S. A. Beresnev, S. Yu. Gorda, G. I. Kornienko, S. V. Nikolashkin, V. A. Poddubnyi, M. A. Tashchilin, "Monitoring of atmospheric aerosol in the Asian part of Russia in 2004 within the framework of AEROSIBNET program," Atmospheric and Oceanic Optics **18** (11), 871–878 (2005).
2. S. M. Sakerin, S. A. Beresnev, S. Yu. Gorda, D. M. Kabanov, G. I. Kornienko, Yu. I. Markelov, A. V. Mikhalev, S. V. Nikolashkin, M. V. Panchenko, V. A. Poddubnyi, V. V. Pol'kin, A. Smirnov, M. A. Tashchilin, S. A. Turchinovich, Yu. S. Turchinovich, B. Holben, T. A. Eryomina, "Characteristics of the annual behavior of the spectral aerosol optical depth of the atmosphere under conditions of Siberia," Atmospheric and Oceanic Optics **22** (6), 566–574 (2009) [in Russian].
3. E. V. Yarkho, "Temporal variability of atmospheric aerosol optical thickness in different climatic zone," Izv. Ross. Akad. Nauk, Fiz. Atmos. Okeana **30** (3), 417–424 (1994) [in Russian].

4. *The Climate of Sverdlovsk*, Ed. by V. V. Morokova and Ts. A. Shver (Gidrometeoizdat, Leningrad, 1981) [in Russian].

5. Yu. V. Shalaumova, V. V. Fomin, and D. V. Kapralov, "Spatiotemporal dynamics of the Urals' climate in the second half of the 20th century," Russ. Meteorol. Hydrol. **35** (2), 107–114 (2010).

6. *Scientific and Application-Oriented Handbook on the USSR CLimate, Ser. 3, Parts 1–6, Issue 9. Perm, Sverdlovsk, Chelyabinsk, and Kurgan Regions and Bashkir ASSR* (Gidrometeoizdat, Leningrad, 1990) [in Russian].

7. S. M. Sakerin and D. M. Kabanov, "Spectral dependence of atmospheric aerosol optical depth in the wavelength range from 0.37 to 4 μm," Atmospheric and Oceanic Optics **20** (2), 141–149 (2007).

8. S. M. Sakerin, V. V. Veretennikov, T. B. Zhuravleva, D. M. Kabanov, and I. M. Nasrtdinov, "Comparative analysis of aerosol radiative characteristics in situations of forest fire smokes and under usual conditions," Atmospheric and Oceanic Optics **23** (6), 451–461 (2010) [in Russian].

9. N. N. Ulyumdzhieva, N. E. Chubarova, and A. V. Smirnov, "Aerosol characteristics of the atmosphere over Moscow from CIMEL Sun Photometer Data," Russ. Meteorol. Hydrol., No. 1, 48–57 (2005) [in Russian].

10. V. N. Uzhegov, D. M. Kabanov, Yu. A. Pkhalagov, and S. M. Sakerin, "Height of homogeneous aerosol atmosphere in the wavelength range of 0.45–4 mcm under different types of turbidity," in *Abstracts of the XVII Working Group "Aerosols of Siberia"* (IOA SO RAN, Tomsk, 2010), p. 107 [in Russian].

11. G. M. Abakumova and E. V. Gorbarenko, *Atmospheric Transparency in Moscow over the Last 50 Years and Its Variations on the Territory of Russia* (LKI, Moscow, 2008) [in Russian].

12. D. M. Kabanov, S. M. Sakerin, and V. V. Veretennikov, "Mean diurnal variation of aerosol characteristics in summer conditions near Tomsk," in *Proceedings of the XVI International Symposium "Atmospheric and Oceanic Optics. Atmospheric Physics"* (IOA SO RAN, Tomsk, 2009), pp. 334–337 [in Russian].

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